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(54) Halftoning pixel processing method by dithering

(57) To convert the multiple-bit-resolution intensity information for a colour component of a given pixel into the ink-on or ink-off command required to control a printer, the source values for different pixels are compared with thresholds in a "dither matrix" of different thresholds for different pixels, and a given pixel is printed if the source value exceeds the dither-matrix value for that pixel. Different dither matrices are employed for different colour components, with the result that lighter-colour areas have a smoother appearance than would result if a common dither matrix were employed for all colour components.

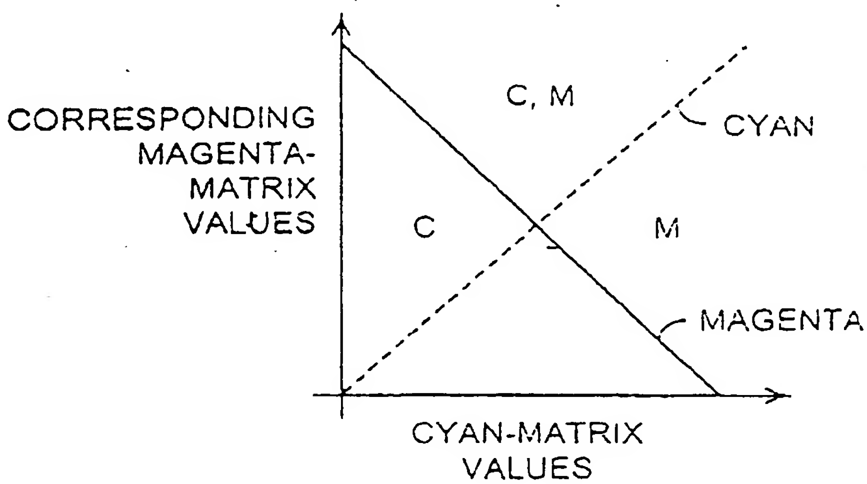

FIG. 4

EP 0 791 895 A2

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The present invention relates to digital display devices such as printers and computer systems that use them. It particularly concerns improving such devices tonal rendition.

At some point or another in the digital processing of an image, the image takes the form of picture-element, or "pixel" values, i.e. image values at discrete locations in the image. Being expressed digitally, those values are necessarily quantised, but they often are nonetheless expressed with a considerable degree of value resolution. The shade of grey in a "black and white" image, for instance, may be expressed with, say, eight bits or more of resolution, so that the pixel may take on any one of 256 or more values. A colour-image pixel value is typically a three-dimensional vector quantity. If each vector component is expressed with eight bits of resolution, a spectrum of over 16 million colours results.

On the other hand, most computer-driven printing devices, such as laser, dot-matrix, and ink-jet printers, op rate in a binary fashion: the output medium is divided into a number of pixels, and the printing device can only print a dot at the pixel location or leave it blank: there ordinarily is no dot-size or intensity choice. In the case of monochrome printers, all of the dots are printed in a single colour. In a colour printer, the same dot can be printed with various combinations of the printer's basic colour components (e.g. cyan, magenta, and yellow) but, again, each component colour has only two values: printed or not.

To render the underlying, high-value-resolution image with such a low-value-resolution device, the high-value-resolution image must be converted into a binary-valued image pattern that the human visual system will tend to integrate to create an illusion of the higher-value-resolution source image. The half-toning process employed in printing for generations performs such a conversion.

A widely employed approach to performing half-toning digitally is called "ordered dithering". Elements of a dither array of predetermined and generally different threshold values are associated with respective image pixels: the array conceptually overlies the image pixel array. If the dither array is smaller than the image array, the dither array is replicated and "tiles" the image array to produce a repetitive pattern. Each pixel thus has two values conceptually associated with it, namely, the requ sted pixel tonal value and the corresponding dither-array element. These two values' comparison yields that pix l's value in the output, binary-valued image.

Many dither-array patterns have been proposed and used, each having its own advantages and disadvantages. The type commonly referred to as "clustered-dot" dithering employs a dith r matrix in which higher values tend to be clust red near other higher values, and lower values tend to be clustered, too. A uniform grey level tends to be rendered in the binary image as clusters of printed pixels, the cluster size depending on the underlying grey value. The resultant image is visually similar to those produced by the traditional half-tone photoengraving screen. An advantage of clustered-dot dithering is that it is relatively forgiving of certain display devices' inability to display isolated pixels.

However, clustered-dot dithering tends not to yield the apparent-grey-scale resolution and spatial-frequency fidelity that "dispersed-dot" dithering affords. The salient feature of this type of dithering is that large and small threshold values are spread throughout the array as evenly as possible. Such arrays tend to achieve relatively good high-spatial-frequency fidelity, and they are also recognised as being capable of relatively fine apparent-value resolution.

This invention provides a method of operating a coarse-pixel-value-resolution display device to render a source image consisting of relatively fine-resolution source colour pixel values, each of which consists of a plurality of relatively fine-resolution source colour-component values, comprising the steps of:

generating source-image signals representing the source colour-component values;
determining output pixel values of an output image consisting of relatively coarse-resolution output pixel values by applying respective dither matrices to respective components of the source image, characterised by the dither matrix applied to at least one of the source-image components differing from that applied to at least one of the others; and
displaying the image by sending the display device instruction signals that include representations of output pixel values thus determined.

Although dispersed-dot dithering is already recognised as affording relatively high spatial-frequency fidelity, the present invention provides a way of providing that advantage to an even greater extent than conventional approaches. Specifically, we employ different dispersed-dot dither matrices for the image's different colour components, and the dither matrices' values are so chosen that the different colours tend to print in different locations. This affords the effect, particularly in more-lightly coloured regions, of yielding a more-continuous appearance.

A way of achieving this result that we prefer for a CMY (cyan, magenta, yellow) colour space is to make each element of the cyan dither matrix the additive inverse (modulo the elements' range) of the corresponding magenta-matrix element, and we make the yellow dither matrix a position-offset version of one or the other of the two dither matrices.

The following discussion of the invention refers, by way of xample only, to mbodiments of the invention shown in the accompanying diagrammatic figures in which:

Figure 1 is a block diagram that constitut s a hardware-type representation of the typical environment in which the present invention is employed;

Figure 2 is a block diagram giving a more software-oriented rendition of that environment;

Figures 3A and 3B depict simple versions of dither matrices of the type that can be used in the present invention;

Figure 4 is a plot of the element values in one dither matrix as a function of the values of the correspondingly positioned elements of another matrix employed in an illustrated embodiment of the invention;

Figure 5 is a similar plot of the relationships among the elements of three matrices that can be employed to implement the present invention's teachings;

Figure 6 is a similar plot of three further matrices that comport with the present invention's teachings;

Figure 7 is a block diagram of a typical relationship between the dither process and generation of binary CMYK signals; and

Figure 8 is a flow chart illustrating one procedure for implementing the present invention.

As the invention description proceeds, it will become apparent that the invention can be embodied in dedicated circuitry designed particularly to implement the invention's teachings. Such an arrangement can be included within a printer that receives instructions in terms of high-resolution nominal colours or grey scales, and the dedicated circuitry can be designed to convert the requested values to the on-and-off or other low-value-resolution instructions required to render the requested image. But the invention will more typically be implemented by a general-purpose machine, such as a personal computer operating as a printer driver, whose purpose is to convert an image expressed in nominal colour values into display-device commands that specify the low-level, typically on-or-off operation of a printer that the computer controls.

Figure 1 depicts a typical hardware environment. A personal computer 10 sends a display device such as an ink-jet printer 12 low-level instructions, i.e., instructions that specify which individual display-medium pixels should receive ink dots. The drawing depicts the printer 12 as receiving these instructions by way of an appropriate channel 14. Computers that are capable of practising the present invention come in a wide variety of configurations, and Figure 1 depicts one in which channel 14 is provided by an input-output adapter 16 with which a central processing unit 18 communicates by way of an internal bus 20.

Of course, the central processing unit 18 will typically f tch data and instructions at various tim s from a variety of sourc s, such as solid-state read-only and read-writ memories 22 and 24. Figure 1 also depicts the computer 10 as communicating, as is typical, with a keyboard 26 by way of an interface adapt r 28.

The present invention particularly concerns display devices within this environment. In this connection Figure 1 depicts the central processing unit 18 as being coupled to a cathode-ray-tube display 30 by a display adapter 32. The computer 10 can employ the present invention's teachings not only to drive printer 12 but also to form an image on the cathode-ray-tube display 30; the broader aspects of the invention are applicable to any pixel-organised display device. But its use on display devices of the cathode-ray-tube type will be infrequent, because present-day cathode-ray-tube computer monitors such as display 30 can provide pixel-value resolution greater than the simple on-or-off choice to which most printers are limited. Although dithering can be practised in a conversion from a high value resolution to any lower value resolution, not merely to binary representations only, the value resolution of which most monitors are currently capable is usually considered adequate. Nonetheless, the present invention's teachings are applicable to digital pixel-oriented display devices generally; they are not limited to ink-jet or other printers.

In the typical situation, the computer 10 implements the present invention's teachings by acting as a printer driver. The instructions that configure the computer to perform this function are usually contained in the operating-system software transferred to the computer's disc drive 38 and stored in a disc that the drive contains. Often, the driver software will have been loaded into the computer system from a diskette or CD-ROM. In any event, the computer 10 reads the printer-driver instructions from the disc drive in most cases and then performs the below-described functions to implement the present invention's teachings.

Figure 2 depicts the typical situation from more of a software standpoint. Typically, the present invention's teachings will come into play when the computer 10 is operating a user's application program 34 and that program makes a system call requesting that an image be printed. The requested operation is carried out by a printer driver 36, which is usually considered to be part of the operating system but is specific to the designated printer. The printer driver's purpose is to convert a device-independent representation of the image into low-level printer instructions that will render that image as faithfully as the printer's limitations permit.

As was stated above, each of a given pixel's colour-value components is expressed as a multi-bit value at some point, but the display device is capable only of either applying that colour component or not in any given pixel; it cannot "paint" the pixel with any greater value resolution than that. (For ease of description, we assume here that the output of the dithering process is to be single-bit values, but those skilled in the art will recognise that the broader teachings of the present invention can be applied to multi-level dithering also). To convert from th high-resolution values to the lower-resolution values to which the display mechanism is limited,

we employ a dither matrix.

Figure 3A depicts a simplified version of such a matrix. For ease of illustration, Figure 3A depicts only a 4 x 4 dither matrix to be used for pixel components expressed in five-bit words, i.e., components that have a thirty-two-value range, from 0 through 31. For dispersed-dot dither, a more representative example would be a matrix of, say, 64 x 64 employed for eight-bit values, which would extend from 0 to 255. To determine which display pixels will receive a dot of a given colour component, the matrix of Figure 3A is conceptually overlaid on adjacent pixels. A single instance of the dither matrix typically does not cover the entire display area, so the matrix is replicated so as to "tile" the display completely.

A given pixel receives a given-colour-component dot if that component's value equals or exceeds the value of the dither-matrix element corresponding to the given pixel. So if, say, the value of the cyan component of the pixel corresponding to the upper-right element of the dith r matrix has a value of 28, that pixel receives a cyan dot. But if the lower-left pixel's cyan component has a value of 28, that pixel receives no cyan dot, because 28 is l ss than the value, 31, of the corresponding dither-matrix element. Still, a pixel value of 28 exceeds most dither-matrix-element values, so in a region whose cyan component is 28 most pixels receive cyan dots. Since the observer's eye integrates the image, the observer perceives a relatively high cyan intensity.

In conventional dispersed dot dithering, the same dither matrix would be employed to determine whether those same display pixels receive magenta and yellow, too. So in a region in which the desire is to portray a light green by requesting cyan, magenta, and yellow values of 6, 0, and 6 respectively, approximately one-eighth of the pixels would receive both cyan and yellow dots and none would receive any other dot combination.

However, we have recognised that a smoother appearance, particularly in light-coloured regions produced by systems whose input value range is, as is typical, an order of magnitude greater than that illustrated, can be achieved by employing different matrices for the different colour components. This is true because the use of different matrices tends to make the different-coloured dots less likely to coincide on the same pixels, so more pixels receive dots: a smoother appearance results because the display medium is less sparsely populated with "painted" pixels.

We therefore prefer to choose the different dither matrices in such a way as to maximise the likelihood that components of lighter colours will not coincide. In our view, this relationship is most important for cyan and magenta. So if Figure 3A represents the dither matrix for, say, cyan, we prefer for the magenta dither matrix to b one such as that of Figure 3B. A comparison of Figures 3A and 3B r veals that the high valu s in the Figure 3A matrix occur in those pixels that have low values in the Figure 3B matrix, and vice-versa. This was achieved simply by subtracting each lement of Figure 3A from the range, 32, for which the dither matrix is intended: in a field of 32 elements, the values in the magenta matrix are the additive inverses of the cyan-matrix elements.

Figure 4 shows this relationship graphically: as the cyan-matrix values increase the corresponding magenta-matrix values decrease. The result is that cyan and magenta dots never coincide in regions in which the average of the cyan and magenta values is less than half the colour-component range. The coincidences that do occur are located only in the darker-coloured areas, where the appearance inherently tends to be smoother, anyway.

If, as we prefer, the cyan and magenta dither matrices are complementary, one cannot create a dither matrix that causes the yellow-dot occurrences to be as disjoint with those of both cyan and magenta dots as the occurrences of cyan and magenta dots are with each other. This is acceptable, since it is not as important from an appearance standpoint for the yellow dots' occurrences to be disjoint with those of the other two components' dots.

Still, there is value in making yellow dots' occurrences as disjoint from the others as possible. To this end, one can generate a yellow dither matrix similarly to the magenta dither matrix generation, namely, by making the yellow dither matrix element a function of the corresponding cyan or magenta matrix elements. For instance, Figure 5 depicts the result of generating the yellow matrix by simply adding half the colour-component range to corresponding values of the cyan matrix. This addition is modulo the colour-component range. Indeed, the magenta and yellow matrices can both be generated in a similar fashion from the cyan matrix, as can be seen in Figure 6, which depicts the results of generating elements of the magenta and yellow matrices by adding one-third and two-thirds, respectively, of the colour-component-value range to corresponding elements of the cyan matrix. Again, this addition is modulo the colour-component range.

It would of course be possible to use either of the above methods using the magenta or yellow matrices as a basis for generation of the other two matrices by addition.

Although any of these approaches is acceptable, we actually employ a somewhat different approach. In an implementation that we have employed, the pixel-component-value range is 0 to 255, while the dispersed-dot-dither matrix that we use is 64 x 64, so each possible element value occurs approximately sixteen times in the matrix. This means that two pixel locations whose cyan and magenta matrix values are the same can have different yellow values. Indeed, we employ an approach that can yield such a result. Specifically, we choos a row and column offset and assign to each location in the yellow dith r matrix th lement value in the cyan-matrix location displaced from that yellow-matrix location by those row and column offsets. The yellow dither matrix

values could alternatively be based on th magenta matrix values at offset locations.

In accordance with the invention's broader teachings, the printer can be operated in a manner that is conventional except for the fact that the different colour components are dithered with different matrices. The particular matrices employed, and the way of insuring that they differ, are not critical to the invention, but the invention is practised most advantageously if, for at least two of the components, less than half the matrix locations have both components' values in the same half of the component-value range.

Figure 7 depicts a typical, but not the exclusive, way to implement the invention. In Figure 7, we assume that the display device is, say, a printer that can print black as well as cyan, magenta, and yellow. Also for the sake of correctness, we will assume that the image is at some point generated or stored in terms of red, green, and blue values instead, and that each colour component is expressed with, say, eight-bit resolution. This is a relativ ly typical arrangement. As part of the printing proc ss, some apparatus, often a personal computer configured as a printer driver for this purpose, performs a wid range of adjustments to which Figure 7 collectively ref rs as a colour-correction step 52.

The particular type of processing that occurs here is not important to the present invention. Since the print r colour agents are subtractive, we have depicted processing 52 for ease of discussion as including conversion from the additive-colour, RGB colour space to the subtractive-colour, CMY colour space, although this trivial conversion actually may not be performed anywhere explicitly. (Determining whether a given CMY component value exceeds a given dither-matrix threshold is equivalent to determining whether the complementary RGB component is less than an inverse threshold value). More substantially, the process will make changes from the nominal colour values to accommodate the limitations of the inks, the paper, etc. in accurately displaying the intended nominal colour. Other accommodations to the paper or other medium may be made, such as limiting the colour darkness (that is, increasing RGB values or decreasing CMY values) to avoid bleeding that can otherwise occur on some types of media. Also, the shapes of the ink spots that a printer actually deposits result in a non-linear relationship between the number of dots deposited and the resultant intensity, and accommodations may be made for these effects.

Regardless of what type of processing 52 is performed, a multiple-bit-per-component colour specification at some point needs to be converted into the binary, ink-or-no-ink command to be sent to the printer. This is the purpose of the dithering process 54, and it is at this point that we us the differ nt matric s for th different components. That is, if w consid r a single component value from each of a given image's pixel values collectively to constitute one image component, the dither matrix that we use to convert from th constituent high r solution values of one source-image component to the lower resolution (typically binary) values of an output-image component differs from that used for the corresponding conversion of at least one of the other image components. The result can then be sent without change to the printer, but instead there is often a CMY-to-CMYK conversion 56. This essentially leaves the resultant binary cyan, magenta, and yellow values unchanged unless they all call for a dot at the same location. The colour that results from printing all three components at the same pixel is black, and it is often considered preferable to substitute black ink. In such cases, the cyan, magenta, and yellow components are reset to zero, and a K (black) component is set to one to command the printer to apply black ink rather than cyan, magenta, and yellow.

Although the invention can be applied simply as Figure 7 illustrates, we prefer in some instances to modify it slightly for those cases in which the medium on which the image is to be printed imposes an ink-duty-cycle limit. As was explained above, part of the processing step 52 may have as its purpose to limit the ink duty cycle by limiting the colour-component values; if values are not permitted to exceed a predetermined limit, the percentage of dither-matrix elements that those values exceed is similarly limited, so the ink duty cycle is, too. That is, certain display pixels correspond to matrix elements that exceed the imposed limit, so, in conventional dithering, imposing that limit will guarantee that those locations never receive dots and the duty-cycle-limitation is thereby observed.

However, our use of different dither matrices for different colour components changes the resultant duty cycle. Since we have so chosen the matrices that a pixel having a high-valued element in one colour component's dither matrix will tend to have a low element value in the dither matrix for a different colour component, a given component-value limit results in much fewer pixels' being guaranteed not to receive dots. So if the image's different colour components are separately dithered, the ink duty cycle no longer satisfies the limitation that a given component-value limitation guarantees when a common dither matrix is employed. To compensate for this effect, we supplement the single-ink limitation by additionally imposing a total-ink-duty-cycle limitation in a manner that will now be described by reference to Figure 8.

Figure 8's blocks 58 and 60 represent separately dithering the three image components in the manner previously described and then performing the CMY-to-CMYK conversion that Figure 7's block 56 represents. But rather than simply sending the results as commands to the printer, we check to determine whether the result was an indication that black should be printed, as Figur 8's block 62 indicates. If so, then th printer is simply instructed accordingly, as before. Oth rwise, the colour-component values are adjusted to impose a total-ink lim-

it, and the dith r proc ss is repeated, as blocks 64 and 66 indicate.

Suppose, for instance, that we have imposed a total-duty-cycle limit of 240%. That is, the total of the duty cycles for cyan, magenta, and yellow cannot exceed 240%. This means that the average of those component values cannot exceed 240% ÷ 3 = 80% of the full-range value. So if the total of the unadjusted values exceeds 240% of the full component-value range, we subtract one-third of the difference from each of the unadjusted components to arrive at adjusted components, whose total value thereby equals the limit, and we dither the result, as Figure 8's block 66 indicates.

We have found that employing this approach yields a much smoother appearance for light colours and thus constitutes a significant advance in the art.

The aforegoing description has been given by way of example only and it will be appreciated by a person skilled in the art that modifications can be made without departing from the scope of the present invention.

Claims

1. A method of operating a coarse-pixel-value-resolution display device (12) to render a source image consisting of relatively fine-resolution source colour pixel values, each of which consists of a plurality of relatively fine-resolution source colour-component values, comprising the steps of:

    generating source-image signals representing the source colour-component values;
    determining output pixel values of an output image consisting of relatively coarse-resolution output pixel values by applying respective dither matrices to respective components Qf the source image, characterised by the dither matrix applied to at least one of the source-image components differing from that applied to at least one of the others; and
    displaying the image by sending the display device instruction signals that include representations of output pixel values thus determined.

2. The method as claimed in claim 1 and further characterised by the colour component values including cyan and magenta values and the respective cyan and magenta dither matrices being additive inverses of one other.

3. The method as claimed in claim 2 and further characterised by the colour component values also including a yellow value and the yellow dither matrix having lem nt values equal to l ment values of a r sp ctive one of the cyan or magenta dith r matrices at an lement location offs t from the yellow element by a preset amount.

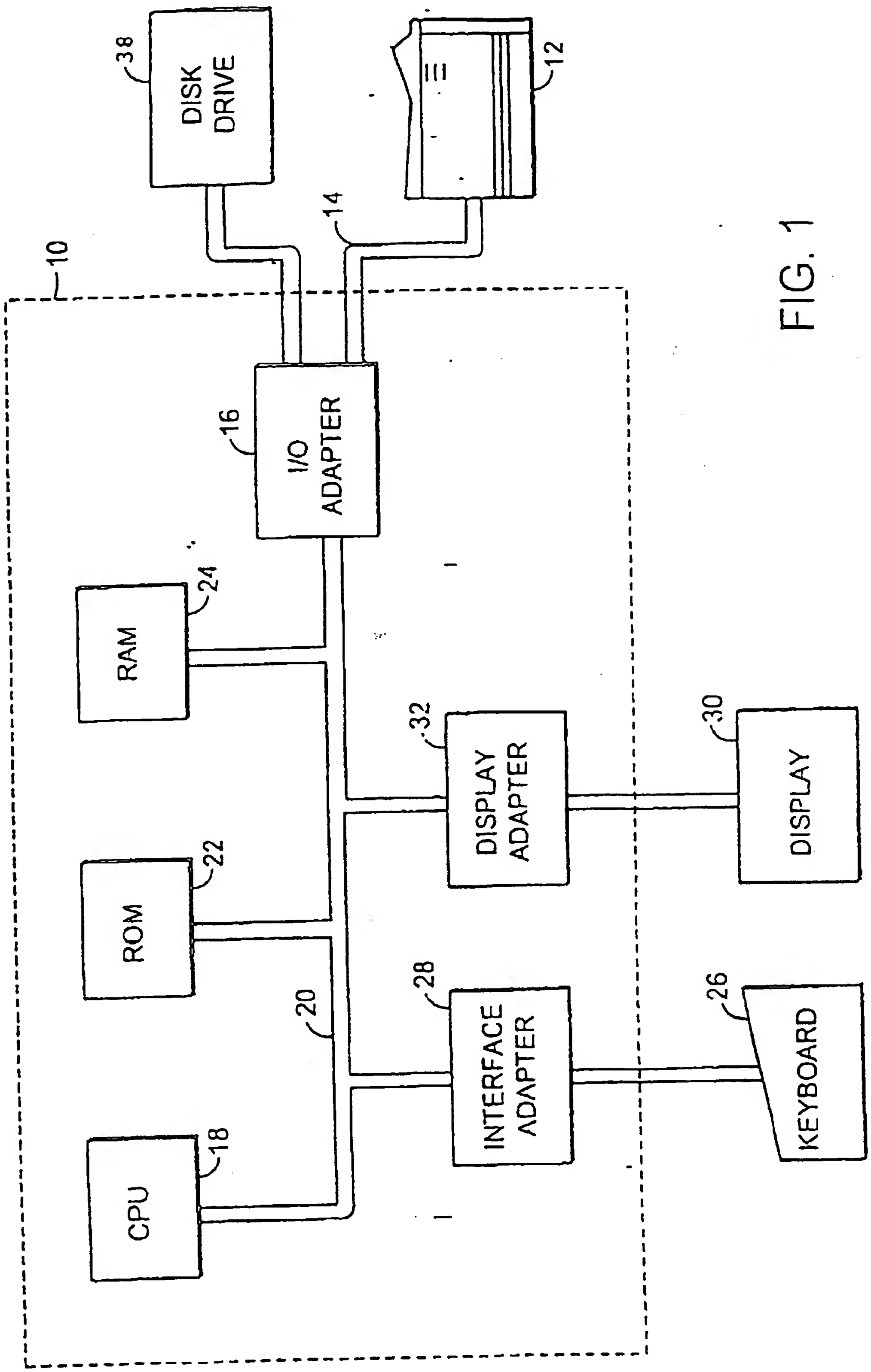
DISK DRIVE
38
12
14
10
I/O ADAPTER
16
RAM
24
ROM
22
CPU
18
20
DISPLAY ADAPTER
32
DISPLAY
30
INTERFACE ADAPTER
28
KEYBOARD
26

FIG. 1

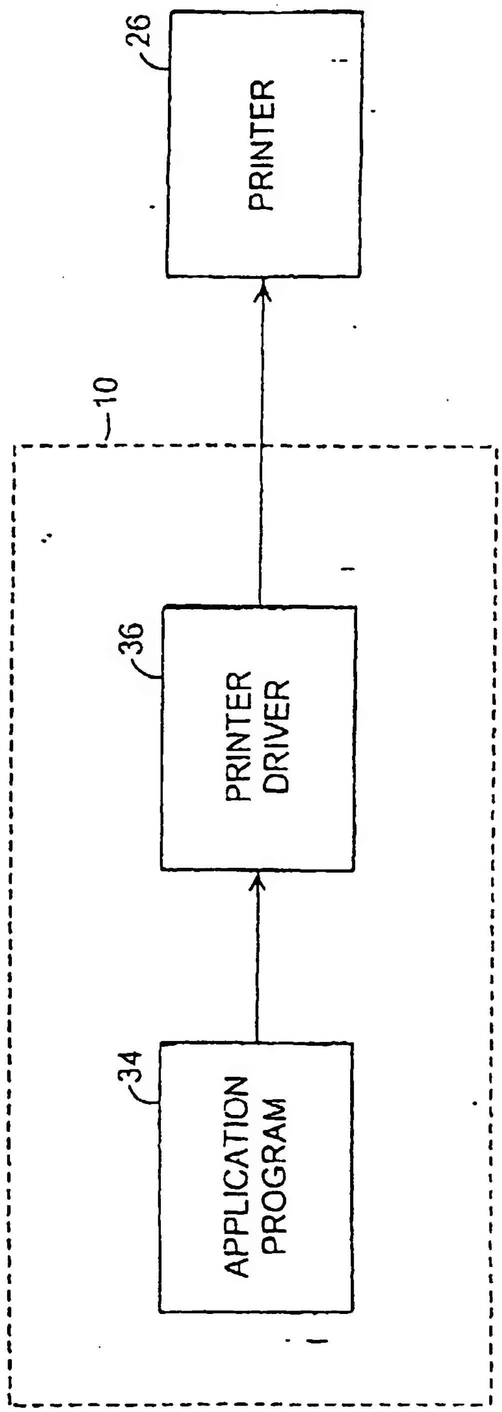

FIG. 2

1	17	5	21
25	9	29	13
7	23	3	19
31	15	27	11

FIG. 3A

31	15	27	11
7	23	3	19
25	9	29	13
1	17	5	21

FIG. 3B

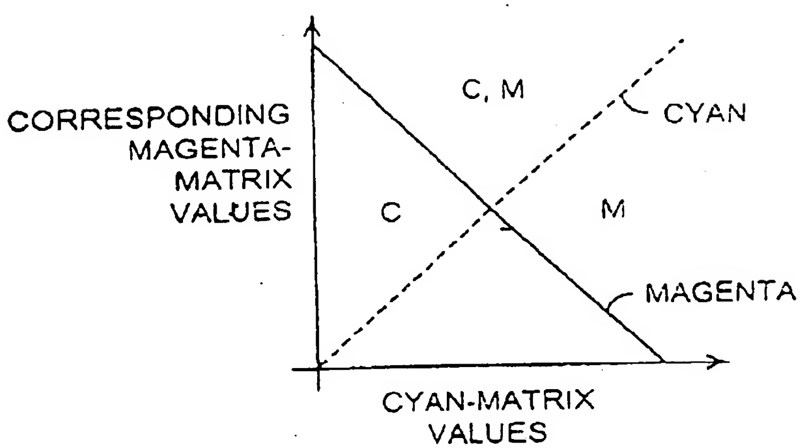

FIG. 4

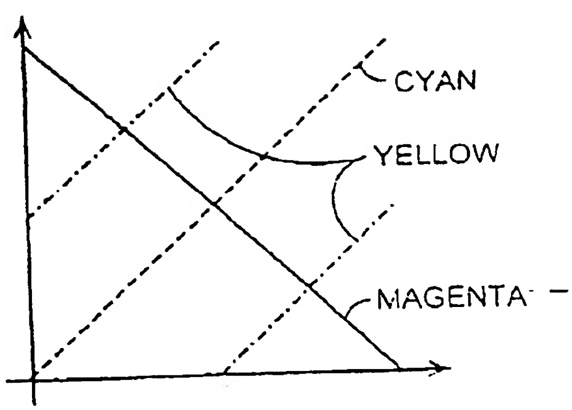

FIG. 5

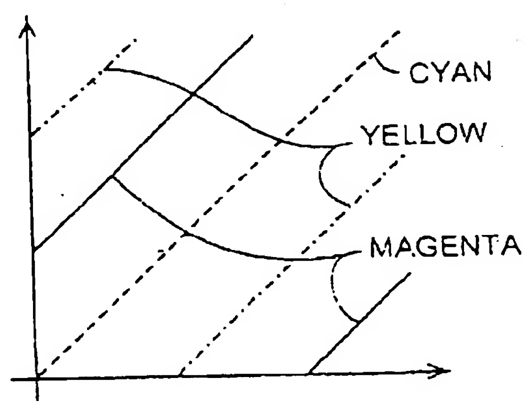

FIG. 6

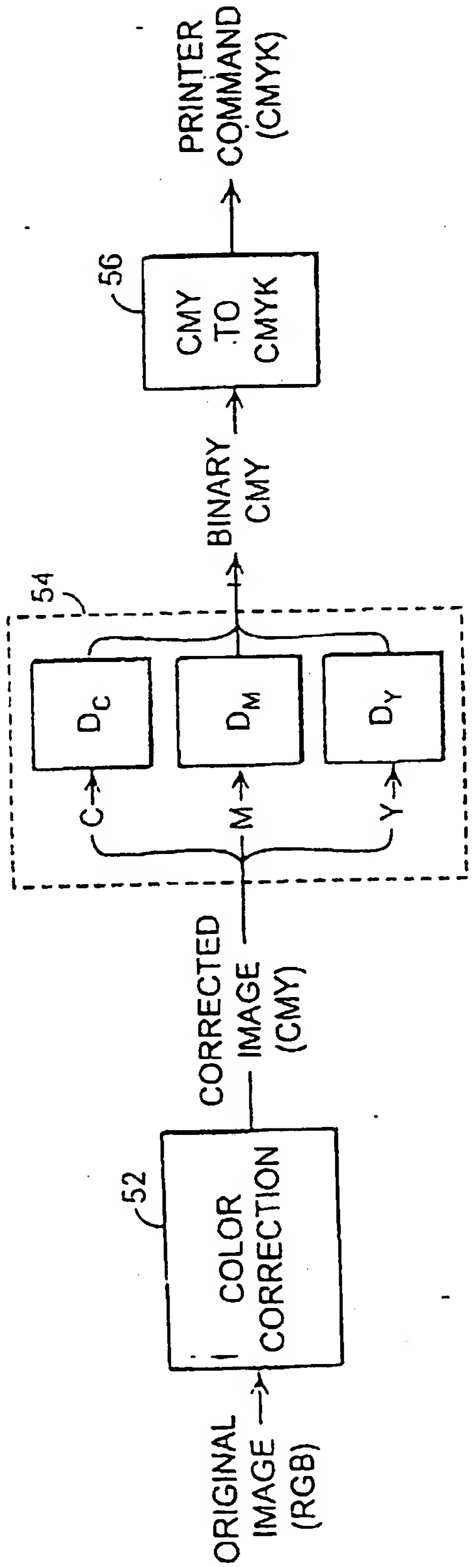
ORIGINAL IMAGE (RGB)
52
COLOR CORRECTION
CORRECTED IMAGE (CMY)
54
C
M
Y
D_C
D_M
D_Y
BINARY CMY
56
CMY TO CMYK
PRINTER COMMAND (CMYK)

FIG. 7

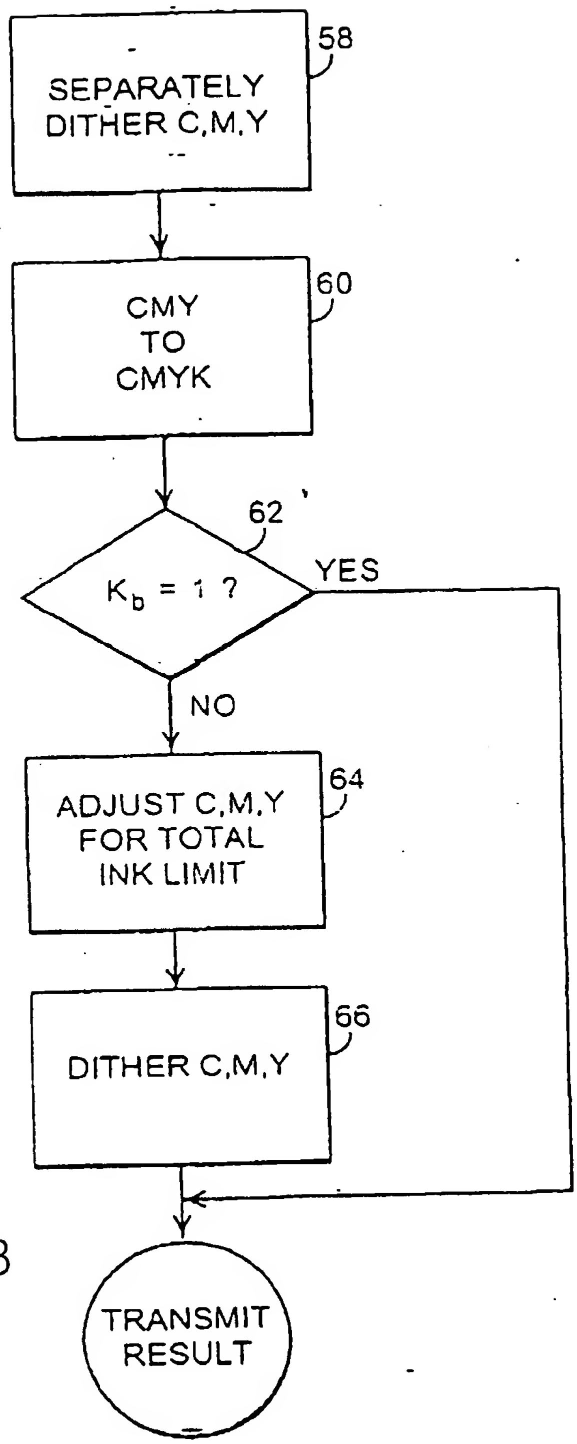
SEPARATELY DITHER C,M,Y
58
CMY TO CMYK
60
$K_b = 1$?
62
YES
NO
ADJUST C,M,Y FOR TOTAL INK LIMIT
64
DITHER C,M,Y
66
TRANSMIT RESULT

FIG. 8

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

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(54) **Halftoning pixel processing method by dithering**

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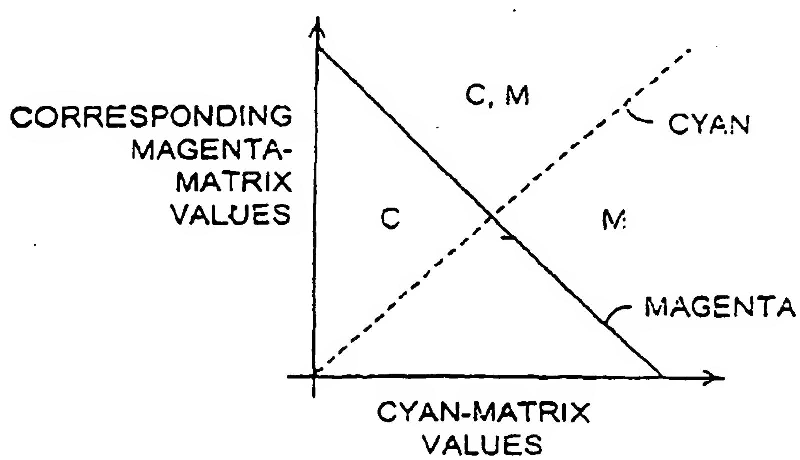

FIG. 4

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Eur pean Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 30 1186

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X Y	US 4 809 063 A (HARUHIKO MORIGUCHI ET AL.) 28 February 1989 * column 2, line 24 - line 42 *	1 2,3	H04N1/52
Y	US 4 595 948 A (TADASHI ITOH ET AL.) 17 June 1986 * column 5, line 57 - line 62 * * column 10, line 9 - line 54 *	2,3	
A	US 5 381 247 A (C. M. HAINS) 10 January 1995 * column 1, line 13 - line 19 *	3	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
H04N

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	15 February 1999	De Roeck, A

CATEGORY OF CITED DOCUMENTS

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EPO FORM 1503 03.82 (P04C01)

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15-02-1999

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